TECHNICAL REPORT NO. 2
Contract No. N-onr-404(03)

June 15, 1953 - June 15, 1954
New Jersey Ceramic Research Station
Rutgers University

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OFFICE OF NAVAL RESEARCH
Contract No. N-onr-404(03)

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Contract N-onr-404(03) Project NR 032 348

I. Introduction

The project was undertaken to exploit the apparent promise of half wave single sheet radomes of dielectric constant of 5 or greater.

Simple considerations of the theory of transmission of electromagnetic radiation through such material indicate that for satisfactory performance extremely close thickness tolerances must be met. The main objective of the project has been to work out the specialized ceramic techniques necessary to allow streamlined radomes to be manufactured to these rigid tolerances.

II. Ceramic Fabrication

A. Operations to Produce Radomes

There are four major ceramic methods available for the fabrication of these shapes. These methods are pressing, extruding, slip casting, and jiggering. Since slip casting showed promise of being the most convenient and practical method, it was the one used during this report period.

B. Ceramic Materials Available for the Fabrication of Radomes

The ceramic material used in fabricating these shapes should have a dielectric constant of 5 to 7 and low loss characteristics. Three materials were taken into consideration.

They were (1) Steatite, (2) Zircon, and (3) Wollastonite compositions. Because it was the most readily obtainable, it was decided to use previtrified steatite and this is the material still in use. The use of previtrified material rather than raw materials greatly simplifies the casting problem and minimized drying and firing shrinkages.

C. Procedure Used in Ceramic Fabrication

1. Milling the Previtrified Steatite

A steel jacketed, porcelain lined ball mill, 22" long and 27" in diameter is used for this operation. Flint pebbles are the grinding medium.

The mill is charged 1/3 full with pebbles and water is added to the halfway mark. A charge of approximately 75 lbs. of the previtrified steatite is placed in the mill. It is found that the preferred form of the steatite is tubular and similar in appearance to spaghetti. The usual steatite plates and discs are to difficult to grind properly.

The batch is ground for 18 hours. After this 18 hour grinding cycle, the mill is opened and the wet milled slurry is siphoned off into enameled trays. These trays are then put into an electrically heated and controlled dryer. Average drying time at 150°F temperature is 4 days.

2. Preparation of Casting Slip

The following batch formula has been used throughout this report period:

Ball Milled Steatite	58,300 gms.
Casting Scrap	19,425 "
Bentonite	777 "
Superloid Gel (10 gms./200 cc H_2O)	785 "
"N" Brand Sodium Silicate (1 cc/10 cc H_2O)	100 cc
Ammonium Hydroxide (26-28%) (1 cc/10 cc H_2O)	500 "
Sodium Hexametaphosphate (24.55 gms/500 cc H_2O)	2,600 "
Distilled Water	31,500 "

The batch is milled for 6 hours in the same mill used for grinding the previtrified steatite.

After grinding, the batch is removed from the mill and run thru a 40 mesh U. S. Laboratory screen.

The batch is then put in a 10 gallon pressure tank with a vacuum pump attached and de-aired for 1/2 hour under a 28 to 29 inch vacuum. From this tank it is run thru a Franz No. 41 ferro filter to remove any tramp iron that may have been introduced into the batch.

The batch is stored in a continuously agitated 50 gallon storage tank for future use.

3. Casting the Shapes

Two piece molds are used for this purpose. A yoke-hoist assembly is used to facilitate handling of the mold.

The following casting procedure is used:

a. The slip is adjusted to a specific gravity of 1.85 and a viscosity of 60 using the No. 3 spindle at 12 r.p.m. of the Brookfield Syncro-lectric Viscosimeter.

b. The mold is filled and allowed to cast for 1 hour and 20 minutes.

c. The excess slip is poured out of the mold and the mold is left in the drain or inverted position for 1 hour to 1 hour 15 minutes.

d. The mold is turned upright and the shape is allowed to dry in the mold for a minimum of 40 hours to a maximum of 70 hours.

e. The shape is removed from the mold and allowed to air dry for 6 to 7 days.

4. Firing of the Shapes

a. Bisque Firing

After the shape has dried sufficiently, it is placed in the kiln and fired to 1800°F in 6 hours and held at that temperature for one additional hour. After cooling for 24 hours the shape is removed from the kiln and sent to the Machine Shop for accurate machining.

b. Final Firing

After the bisque shape has been machined to the desired wall thickness, it is again fired in the kiln. This time it is fired to 2200°F in 7 hours and held at that temperature for one additional hour.

c. Defects

Thus far the main defect seems to be warpage which is not apparent until after the final fire. This consists of out of roundness at the base and a movement off center of the tip of the shape. A lower firing temperature of 2180°F seems to overcome this to some extent without any undue affect on the vitrification of the shape.

d. Drying and Firing Shrinkage

(1) Drying and Bisque Shrinkage

Since it is almost impossible to handle the shape and accurately measure it before the bisque fire, it has not been possible to obtain very accurate measurements. All indications point to an overall shrinkage from the mold to the bisque of 5% approximately.

(2) Shrinkage of Bisque to Final Fired

Since it is possible to obtain accurate measurements in this step, we have more accurate shrinkage data.

Following is the shrinkage information obtained from firing a number of machined shapes.

	Bisque	Final Fired	% Shrinkage
Dome A			
Height	36.881"	33.303"	10.7
Outside Dia.	9.160"	8.354"	9.7
Inside Dia.	8.808"	8.029"	9.7
Wall Thickness	0.176"	0.161"	9.3
Dome B			
Height	37.150"	33.629"	10.4
Outside Dia.	9.296"	8.503"	9.3
Inside Dia.	8.820"	8.071"	9.1
Wall Thickness	0.238"	0.216"	10.4
Dome C			
Height	36.537"	32.235"	13.3
Outside Dia.	9.282"	8.264"	12.2
Inside Dia.	8.762"	7.833"	10.5
Wall Thickness	0.260"	0.216"	15.7
Dome D			
Height	35.740"	31.506"	13.4
Outside Dia.	9.072"	8.103"	12.0
Inside Dia.	8.490"	7.571"	12.1
Wall Thickness	0.291"	0.261"	11.5
Dome E			
Height	35.836"	31.795"	12.7
Outside Dia.	9.020"	8.023"	12.4
Inside Dia.	8.426"	7.498"	12.4
Wall Thickness	0.297"	0.262"	13.4

	Bisque	Final Fired	% Shrinkage
Dome F			
Height	35.656"	31.818"	12.1
Outside Dia.	8.923"	8.014"	11.3
Inside Dia.	8.320"	7.490"	11.1
Wall Thickness	0.301"	0.262"	14.9
Dome G			
Height	35.628"	31.898"	11.7
Outside Dia.	8.923"	8.019"	11.3
Inside Dia.	8.320"	7.486"	11.1
Wall Thickness	0.302"	0.266"	13.5

The % shrinkage is based on the fired size.

Due to the warpage encountered in the final fired shapes, the inside and outside diameters are the average of the maximum and minimum measurements.

III. Machining Ceramic Shapes

A. Experimental Test Shape No. 3

All the work, during this report period, was done on Experimental Test Shape No. 3 (Fig. 1).

Since this shape is relatively simple in design, it was decided to work on it first in order to develop our machining techniques as rapidly as possible. It is expected that in the very near future more complicated ogive shapes will be produced.

B. Setting Up for Outside Machining

A special Arbor (Fig. 2) was designed to fit inside the bisque ceramic shapes. The shapes were then placed on this arbor and then fastened to the face plate of the lathe with four

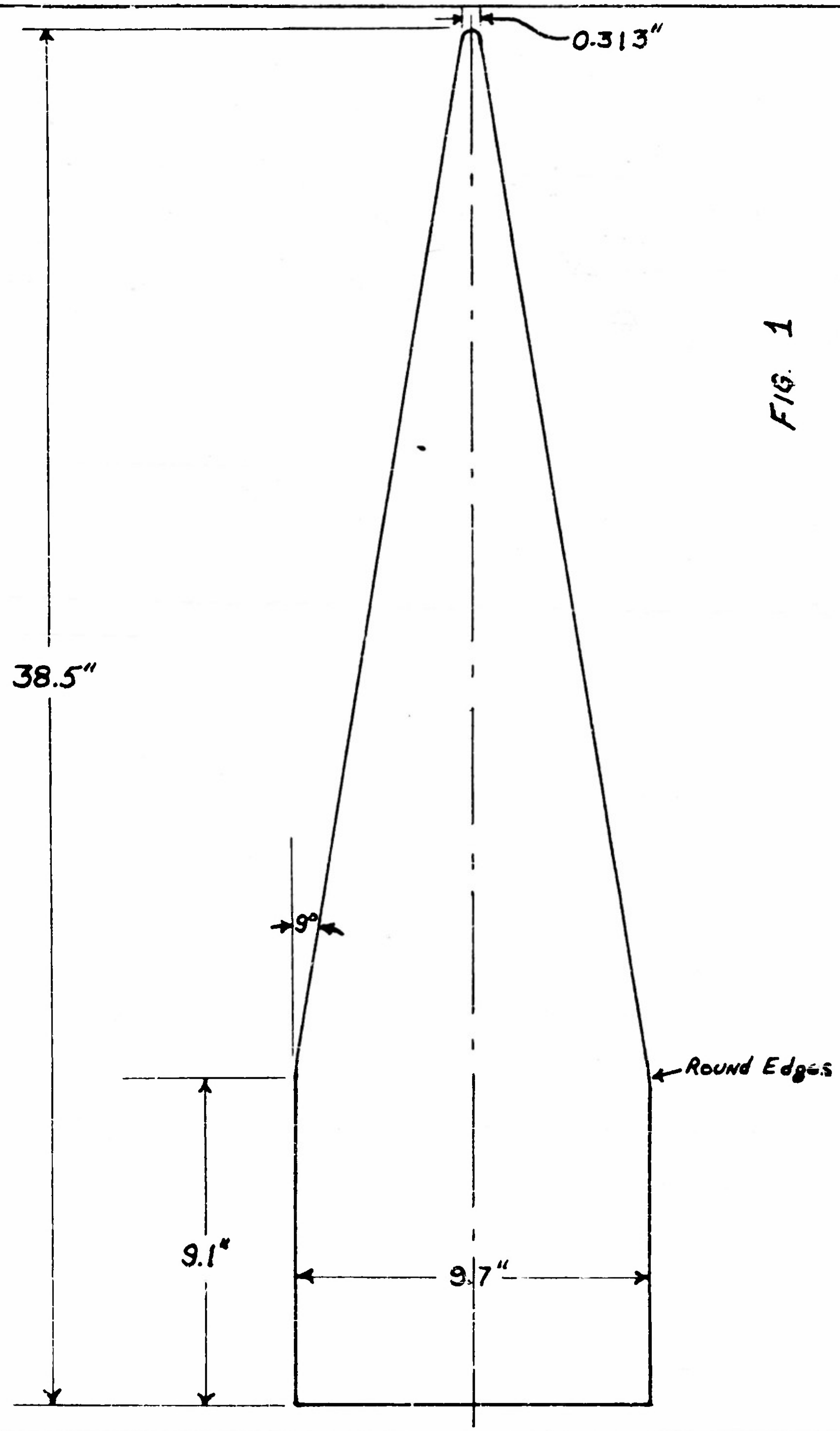


FIG. 1

EXPERIMENTAL TEST SHAPE NO. 3.
ALL DIMENSIONS COMPENSATED TO
MOLD SIZES.
Scale 3" = 1' DWG. NO. 404(03)-7

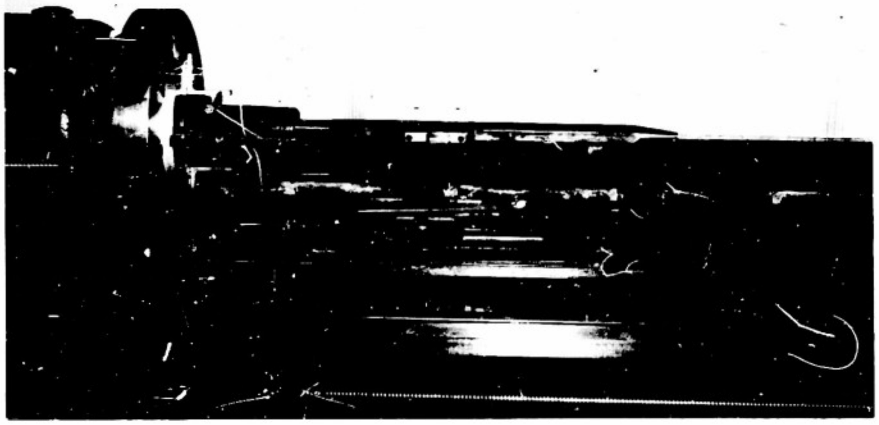


FIG. 2

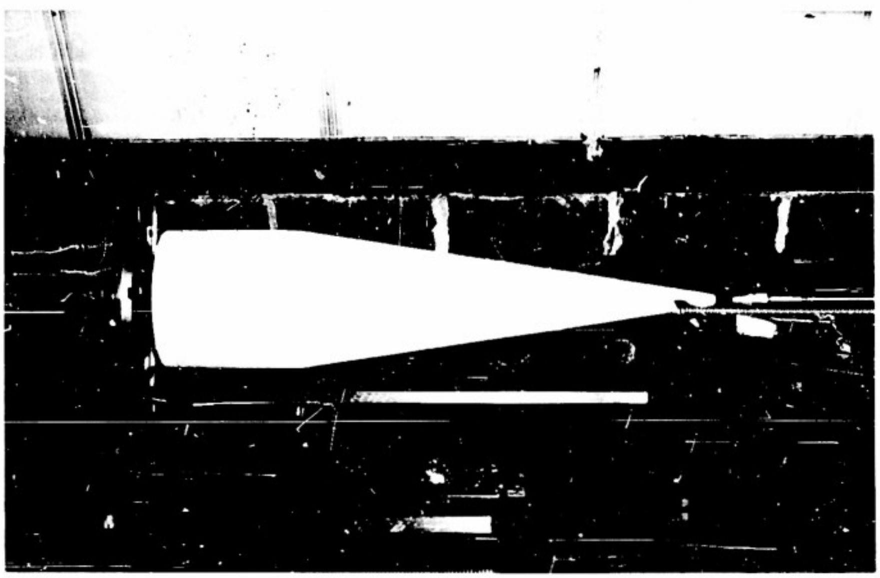


FIG. 3

fingers that gripped a 1" flange at the base of the shape. The shape was then centered as accurately as possible by adjusting these four fingers.

The next step was to turn down the first 3 or 4 inches at the point of the shape until this section was perfectly symmetrical. The point was then placed in a free center and the shape was ready for complete outside turning as indicated in Fig. 3.

C. Outside Machining

The necessary guide template was made to guide the tool. This follow plate was used for both outside and inside machining.

The first machining was done without lubricant and using Carboloy bits of Kenna Metal No. KH. In this manner, it was possible to take cuts of 0.020" to 0.040" in diameter. This necessitated taking 12 to 15 cuts on each outside diameter and it required 53 minutes to complete each cut. Tool wear was also excessive (0.003" to 0.004" per cut).

It was next decided to try to speed up this machining by the use of diamond tool bits. Imperfect white diamonds were purchased for this purpose and the next attempts were made using them.

There were no apparent advantages in the use of these diamonds. The diamonds showed quite a bit of wear and were quite brittle and chipped on the first pass when the shape was not symmetrical and uneven pressures were exerted on the diamond tip. Since we have no facilities for sharpening diamonds, this caused undue delay.

Due to the fact that they were more convenient to work with, it was decided to return to Carboloy cutting tips. This was done and thru testing, it was found that Carboloy No. 78B was the best for our purpose. This tip is still in use.

It was next decided to try to speed up the machining by using grinding wheels. Aluminum Oxide and Silicon Carbide wheels of various grain sizes and one Diamond Wheel were tried. The Aluminum Oxide wheels were first tried dry and then with water for a coolant. The Silicon Carbide and Diamond Wheels were tried using a coolant only. These wheels were first mounted on a 1/2 H.P. Dumore Grinder, however this was not powerful enough and it was found necessary to set up a Master Lathe Converter for this purpose.

The Aluminum Oxide wheels did not prove satisfactory at all. Various speeds and feeds were tried without satisfactory results. The wheels were slower cutting than the carboloy tools and all cuts showed the results of considerable chattering and had a very wavy surface.

The Silicon Carbide wheels with the use of coolant showed some improvement over the Aluminum Oxide, but were still far from satisfactory. Various grain size wheels were used the coarser grained wheels appeared to give the best results.

The Diamond Wheel proved to be the best. It, however, did not cut as fast nor leave as smooth a surface as the Carboloy tools. A collant was also used with this wheel.

It was then decided to go back to the Carboloy tips and try deeper cuts with the aid of the coolant used in conjunction with the Silicon Carbide and Diamond Wheels. This proved most satisfactory. Using this method, it was possible to take rough cuts up to 0.250" in diameter and cut the time per cut to 35 minutes. This cutting also left a very smooth surface on the shape.

D. Final Truing of Dome Point

After the shape has been turned down to the desired dimension, it is necessary to finish turning the point and to blend the cut with the rest of the shape. This is accomplished as shown in Fig. 4.

E. Inside Machining

In order to hold the shape securely for this operation, the steady rest shown in Fig. 5 was designed. This fixture was originally designed with an aluminum bearing turning in side brass shoes. This proved unsatisfactory as the brass shoes wore excessively.

The fixture was then modified by having a steel ring sweated on the aluminum and replacing the brass shoes with bronze. Although the wear problem was mostly eliminated in this manner,

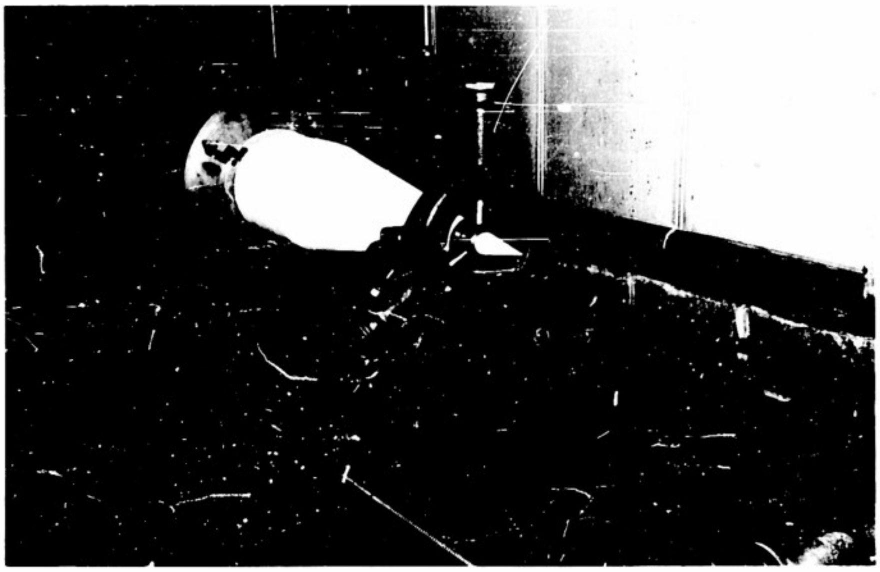


FIG. 4

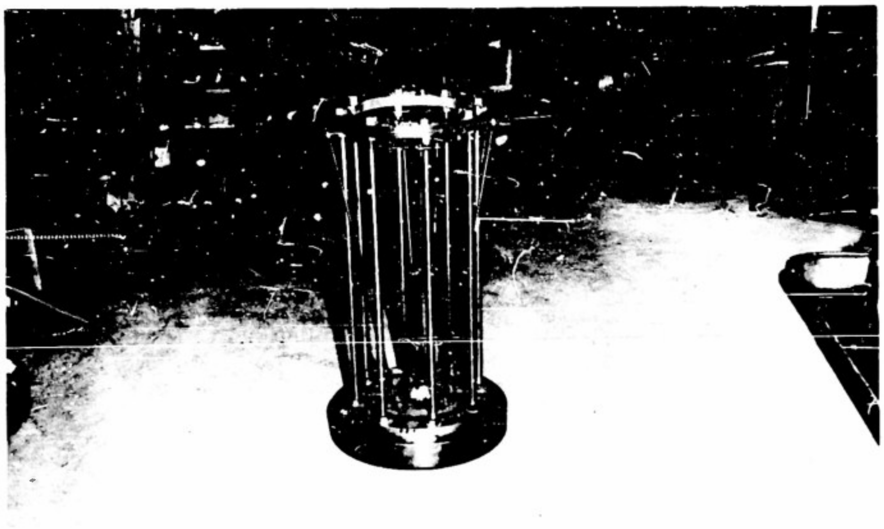


FIG. 5

the lathe speed was limited to 98 r.p.m. Any faster speed caused excessive heating of the ring and consequent loosening of the shape in the fixture.

The fixture was next modified by replacing the bronze shoes with ball bearings. This proved quite satisfactory as wear is almost eliminated and lathe speed was increased to 121 r.p.m.

Next, the boring bar shown in Fig. 6 was designed along with the necessary boring tools. This boring operation is at present a four step operation as follows:

1. The nose of the shape is reamed out using a reaming tool with the desired taper.
2. A Carboloy cutting tool then cuts the inside from the reamed nose to approximately two-thirds of the way down the cone. (Fig. 7)
3. Another Carboloy tool then blends this cut and carries on to within 3 inches of the 1" flange on the cylinder of the shape.
4. A third tool then finishes the remainder of the shape.

Thus far all the inside cutting has been done without the use of coolant. This will be attempted next in an effort to speed up this part of the machining, since due to the present limitations in cutting speed and depth of cut this is now a 2 to 3 week operation. Fixtures are now being prepared for the use of coolant in this part of the operation.

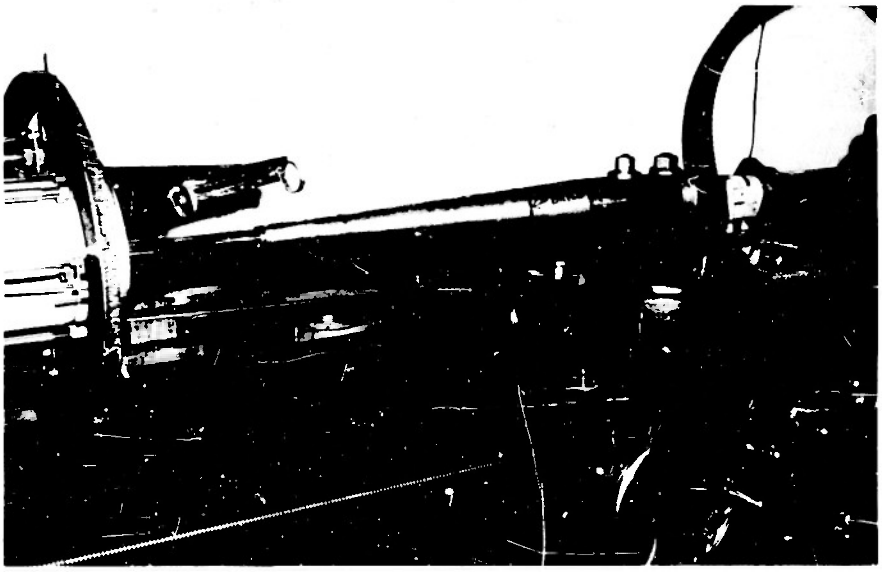


FIG. 6

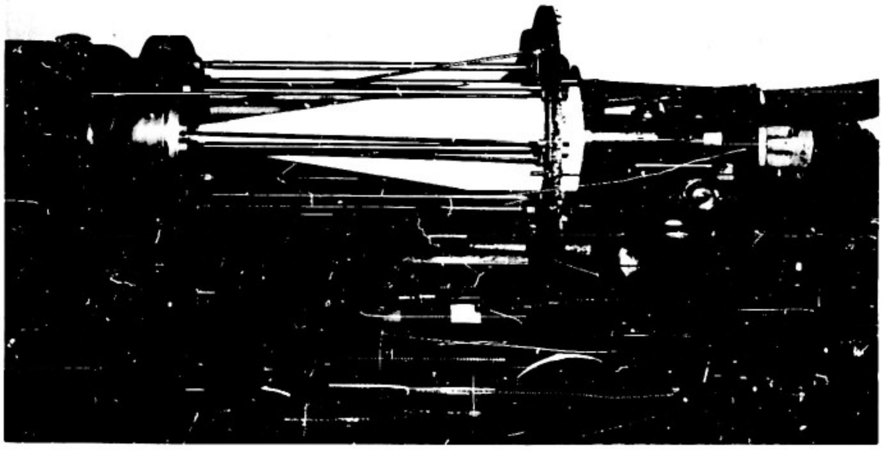


FIG. 7

F. Final Cut Off Operation

After machining, the bisque shape is refired to vitrification and then returned to the Machine Shop for this last operation.

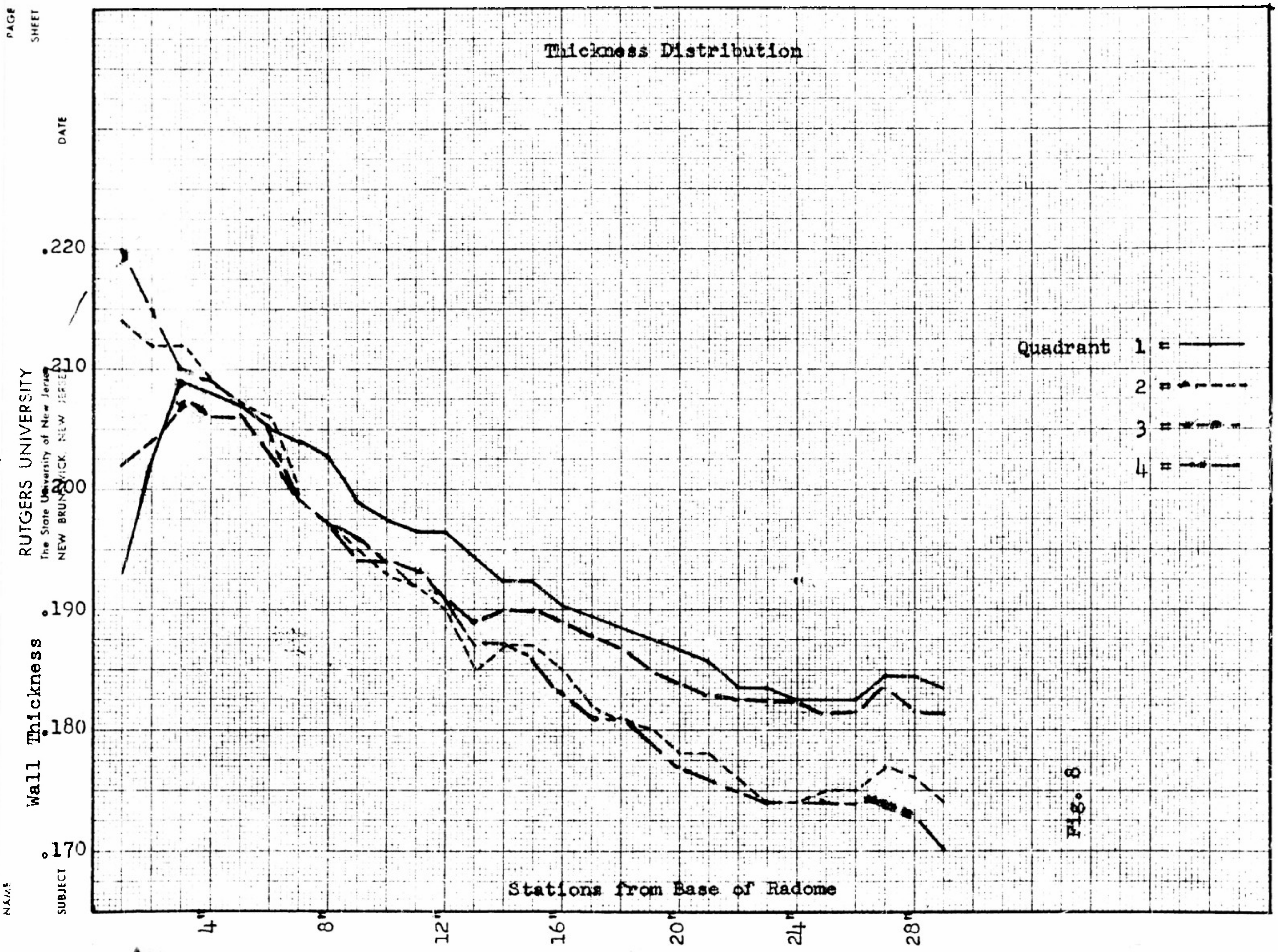
The shape is placed in the steady rest for this operation. It is held at the cylinder end by four clamps. The point is placed in a sleeve which holds the cone about 6 inches from the tip. The shapes showed some warpage in the final firing which caused the point of the dome to be off center. Therefore, this arrangement was found necessary to allow some free movement of the tip without danger of it breaking off.

A Diamond impregnated saw is then used to cut off approximately 2" of the cylinder end and the one inch flange. This finishes the machining operations.

G. Wall Thickness Distribution

The included two charts (Figs. 8 and 9) show the Thickness Distribution in the walls of 3 domes. At present, it is impossible for us to obtain these measurements and an outside source was used to obtain them. These charts are listed chronologically in the order of their delivery to this source.

It is expected that in the near future it will be possible for us to obtain these measurements accurately ourselves. An instrument for this purpose is now on order. This instrument is so designed as to enable us to take measurements without removing the shape from the machine.



Thickness Distribution
Quadrant 1 =
2 =
3 =
4 =
.220
.210
.200
.190
.180
.170
Wall Thickness
4"
8"
12"
16"
20"
24"
28"
Stations from Base of Radome

Fig. 8

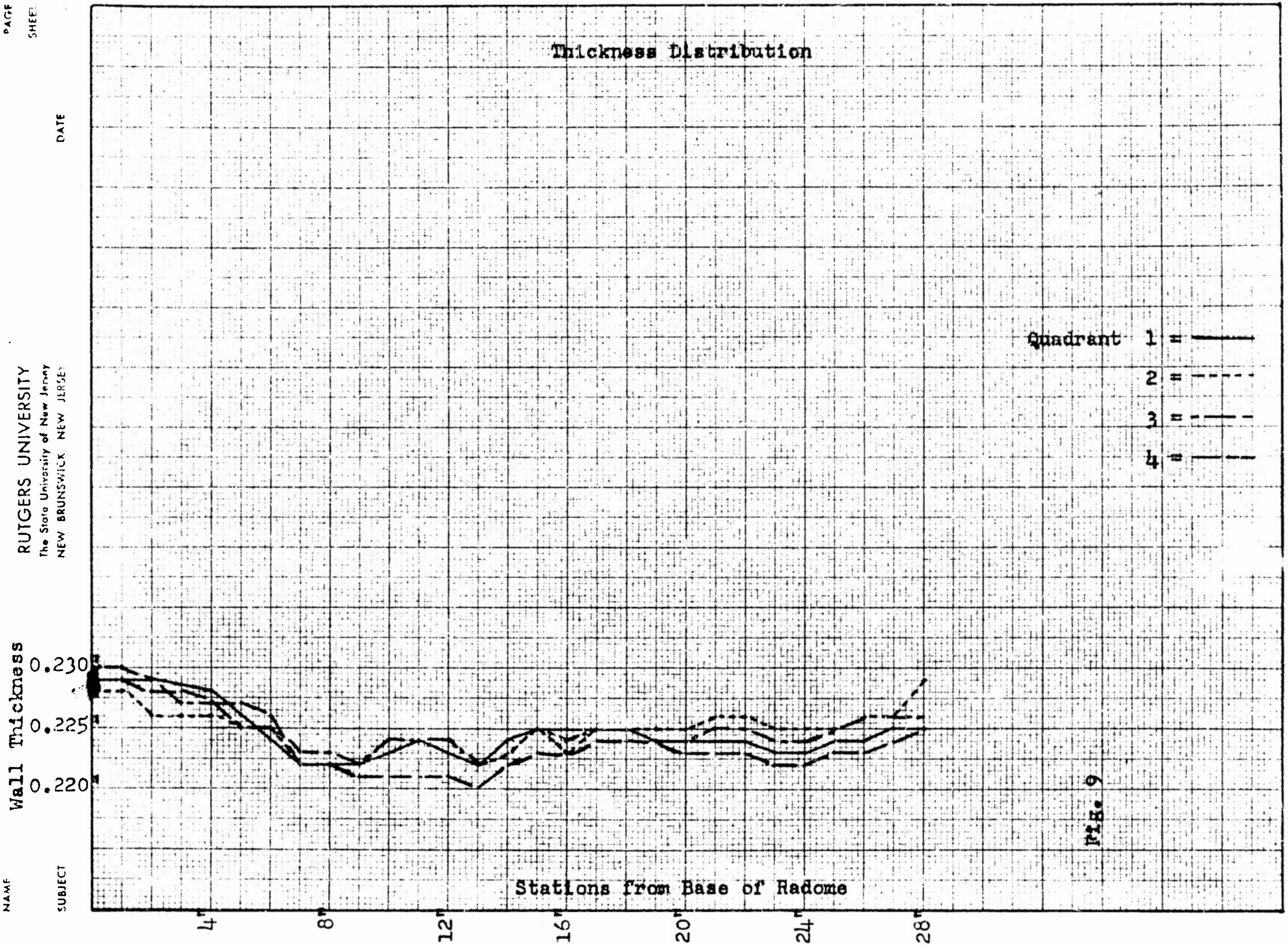

Thickness Distribution
Quadrant 1 =
2 =
3 =
4 =
Wall Thickness
0.230
0.225
0.220
4"
8"
12"
16"
20"
24"
28"
Stations from Base of Radome

Fig. 9

IV. Testing of Finished Shapes

While there is no thought of setting up at Rutgers the elaborate electronic equipment necessary for the measurement of the effects of the finished radomes on the beam of electromagnetic radiation passing through them yet, we are vitally interested in evaluating the shapes we make from this standpoint.

Through the kindness and cooperation of the Raytheon Manufacturing Company, some measurements have been carried out in transmission and beam deflection on radomes made at Rutgers.

Because of our present, but temporary, inability to measure directly the thickness of radomes while they are still in the machining process there has been some difficulty in hitting exactly the specified thickness. The first shapes sent for testing were about 0.050" below the specified optimum thickness and the results as might be expected were not good. Later shapes, still about 0.015" too thin, gave very much better results with maximum error rate of about 0.1 degree per degree and transmissions around 90%. These results seem good enough, even with the lack of thickness control which will soon be corrected, to lend tremendous encouragement to the whole program.

If, already, we are approaching the electromagnetic performance of good plastic radomes it would seem that the low dielectric loss obtainable with ceramic materials together with their resistance to high temperatures would justify a very determined effort to produce a ceramic radome which can be flight tested. That is our goal now.

V. Future Work

In general, an effort will be made to improve each phase of the operations necessary to produce radomes within specified tolerances as follows:

A. Present machining procedures will be improved with an eye to more accurate and more rapid machining.

B. Test equipment, necessary to check the uniformity and reproducibility of the dielectric properties of the material, will be procured.

C. New shapes are now under consideration and will be fabricated and tested as rapidly as possible.

D. The testing of the shapes will be conducted with the cooperation of various organizations equipped to make these tests.

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